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ORIGINAL PAPER

Longitudinal growth strains in five clones of *Eucalyptus tereticornis* Sm.

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Abstract: We studied the variability in longitudinal growth strains and wood basic density in five-year old trees from five clones (one tree per clone) of *Eucalyptus tereticornis*. Mean longitudinal growth strain in clones ranged from 466 to 876 µm. There was a significant difference between clones in growth strains and wood basic density. Clone 10 exhibited maximum growth strains and basic density, whereas clone 3 and clone 7 exhibited minimum growth strains and basic density, respectively. Within a tree, the growth strain variation with tree height was high but statistically insignificant while within tree variation in basic density was very small. There was no specific trend in variation in either strain or density within a tree. There was 5%–200% difference in growth strain on opposite sides of the logs. However two strains showed a strong positive correlation. There was a moderate positive association of wood basic density and mean growth strains in logs. The variation around the periphery emphasize the need to measure strain more than one, preferably on opposite sides at the same height, on a tree to know the mean strain level for the purpose of selection of clones.

Keywords: basic density; clone; eucalypts; growth stress; strain gauge

Introduction

Plantation species, especially *Eucalyptus* sp., are widely planted in temperate, tropical and subtropical regions, because of their high productivity on marginal sites and their ability to produce a range of useful forest products. India has the largest eucalypt plantations in the world with an area of 3.94 million ha (Chezhian et al. 2010). *Eucalyptus tereticornis* Sm. is a preferred species in these plantations because of its fast growth, wide adaptability to varied climatic conditions and relatively high resistance to drought (Rao et al. 2002). Most eucalypt plantations are established to meet the growing demand for pulpwood. Therefore, eucalypt improvement and breeding programmes have focused on faster growth, high yield and to a certain extent on fiber qualities, which are of significant economic importance for paper industries (Lal 2003; Gomide 2009; Ramirez et al. 2009).

In recent years, there has been growing interest in obtaining higher value solid wood products from eucalypt plantations due to declining availability of conventional timber species (Sharma et al. 2005; Pelletier et al. 2008; Chauhan and Aggarwal 2010). A major constraint in utilization of plantation *Eucalyptus* sp. is the presence of high growth stresses. The high magnitude of growth stresses cause end cracking immediately on felling trees, brittle-heart in logs, and warping on sawing, resulting in processing problems and low recovery of defect-free sawn timber. Paradoxically, there is no direct practical method available to measure growth stresses in trees or logs. Therefore, strains on the cambial surface are measured on releasing the growth stresses and these strains are considered to be an indicator of stresses as strain is proportional to the stress within the elastic limit. Most of the early research on growth stresses concentrated on methods of strain measurement in logs and standing trees, understanding its variability within and between trees/plantations (Kubler 1987; Chauhan and Walker 2004). Subsequently, there were efforts to reduce or control the ill effects of growth stresses either by storing logs under water for long time periods, heating or by adopting complex sawing methodologies, but most of these are not practicable.

One of the ways to address the issue is to grow trees with inherently low stresses. It has been recognized that longitudinal growth strains are genetically controlled to a large extent. The broad-sense heritability in growth strains have been reported in the range of 0.3 to 0.5 (Henson et al. 2004, Murphy et al. 2005). Very high heritability has been reported for end-splitting in logs (a consequence of high growth stresses) of *Eucalyptus urophylla* and *Eucalyptus grandis* (Garcia et al. 2001). Santos et al. (2003) observed significant genetic variation in basic density, bowing of sawn wood (an indicator of growth strain), heartwood percentage, and modulus of elasticity in 41 open pollinated progenies of *Eucalyptus grandis*. Gerard et al. (1995) documented the influence of genotype on magnitude of inherent growth strains in several species of eucalypt. The genetic control on this property

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provides an opportunity to use this trait for selection in breeding. The absence or low level of end splitting in logs was an important criterion in the tree-breeding programme in South Africa (Malan 1995). Henson et al. (2004) took the low growth strain as one of the selection criteria for screening families of *Eucalyptus dunnii* for solid wood production. Clonal forestry can play a significant role in achieving quick genetic gains targeting growth stresses by propagating specific clones having low stress levels.

In this study, we report growth strain variation in five clones of *Eucalyptus tereticornis*. These clones were designated as some of the best of 35 clones in terms of productivity and have been evaluated for pulp quality (Rao et al. 1999) and also for mechanical properties of wood (Kothiyal et al. 2002). We quantified variation in growth strain along the height of the tree and around the periphery. We also explored the relationships between longitudinal growth strain and log diameter and basic density.

Materials and methods

Logs from five clones numbered 3,4,6,7 and 10 supplied by ITC Bhadrachalam Paperboard Ltd. were examined. These clones were grown in black soil under rain-fed conditions. The trees were about 5 years old at the time of the study and one tree was cut from each clone. These trees were part of a long term experimental trial and therefore only a single tree per clone was available for destructive testing and evaluation. At the time of felling, trees had attained heights of 14−15 m (clones 4, 6 and 7) and 17−18 m (Clones 3 and 10). The trees were nearly cylindrical without much taper. Billets of 1 m length up to a height of 5−6 m, were cut from each tree. Diameter (with bark) of each log was measured at mid point. Both ends were coated with thick black paint to avoid any moisture loss and transported to the laboratory. The logs in laboratory were kept under continuous water spray to keep them in wet condition until measurements were initiated to avoid development of any additional drying stresses in the wood. We first cut and debarked one disc of 25 mm thickness from both the ends of each log. These discs were immediately measured for weight and volume. The green volume was determined using Archimedes principle by measuring disc weight in water to an accuracy of 0.1 g. These discs were then oven-dried (OD) at 103 ± 2 °C until they attained a constant weight and then weighed to an accuracy of 0.1 g. Wood basic density (BD) was determined using the following formula (Walker 1996).

$$BD = \frac{OD\ weight}{Green\ volume} \tag{1}$$

Longitudinal growth strains (LGS) were measured at the mid-point of each log using a strain gauge (Aggarwal et al. 1998). Because log diameters ranged from 8−12 cm, strain measurement at the mid-point of the logs (1 m length) were largely unaffected by the strain release of cross-cutting as strains up to 3 times the log diameter are reported to be influenced by cutting the log (Kubler 1987). The procedure of strain measurement was as follows.

A portion of the bark from the vicinity of measuring point of the log was removed to expose the wood surface. The wood surface was thoroughly cleaned using cotton to wipe surface moisture. A 5-mm wire strain gauge of 350 ohms resistance was glued to the exposed wood surface using a cynoacrylate based adhesive. After gluing, the adhesive was allowed to cure for about 30 minutes to get effective bonding of the gauge to the wood surface. After the stipulated time, wood fibers were cut above and below the strain gauge using a hand drill to release the tensile stress in the fibers. The cut slots were about 15 mm wide and about 20 mm deep. The edge of the slot close to the gauge was about 15 mm from the centre line of the gauge**.** Slots were made in small increments up to a depth till a constant value of longitudinal growth strain was achieved. As the slots were made, cut fibers contracted longitudinally and expanded transversely. Change in strain in the immediate vicinity of the gauge was recorded by a purpose-built strain measuring device. The configuration of holes and strain gauge is shown in Fig. 1.

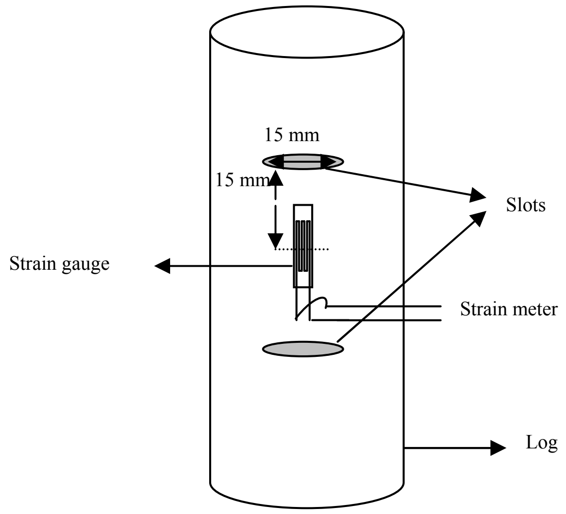

Fig. 1 Configuration of strain gauge and holes

Data were analyzed using SAS statistical software (SAS ver. 9.0). Analysis of variance (ANOVA) was performed to quantify differences within and between clones. Fisher's least significant difference test was used to analyze differences between clones.

Results and discussion

The average values of log diameter at mid point, longitudinal growth strain and basic density along with coefficients of variations (in parentheses) are given in Table 1. Significantly different clones at α=0.05 are shown by different superscript letters. The results of analysis of variance between clones and within trees for each variable are presented in Table 2.

Log diameter, growth strain, and basic density were highest in clone 10. Mid-point diameter of the sampled logs varyied from 10.3−14.2 cm. Mean tree growth strain in clones ranged from 466−876 μm. Mean wood basic density ranged from 539−593 kg·m^{-3}. Variability in basic density within trees was very small as indicated by very low coefficients of variation.

Table 1. Average values of measured variables for five clones

Clone No	Diameter (cm)	Avg. LGS ($\mu m \cdot m^{-1}$)	Basic density ($kg \cdot m^{-3}$)
3	10.9 (13.6)^{a}	466 (38.7)^{a}	557 (4.3)^{a}
4	12.8(6.3)^{b}	602 (30.7)^{a}	548 (2.9)^{a}
6	12.9 (8.8)^{bc}	640 (21.7)^{ac}	556 (2.4)^{a}
7	10.3 (7.8)^{a}	491(57.7)^{a}	539(2.0)^{a}
10	14.2 (9.7)^{c}	876 (31.2)^{bc}	593 (3.7)^{b}

Table 2: Analysis of variance for each variable

Variable	Source	df	SS	MS	F stat.
Diameter	Between clone	4	58.49	14.62	12.26***
	Within tree	5	14.62	1.69	1.28
LGS	Between clone	4	636910	159227	3.11*
	Within tree	5	213260	42652	0.83
Basic density	Between clone	4	0.010	0.0025	8.64***
	Within tree	5	0.002	0.0004	1.58

Growth strains and basic density did not differ between clones 3, 4, 6 and 7. The results on basic density variation within and between clones corroborate the findings of Kothiyal et al. (2002), who characterized the same clones for mechanical properties. Between clone differences were highly significant for log diameter and basic density ($p < 0.001$), and significant ($p < 0.05$) for growth strains. None of the variables exhibited statistically significant variation within trees. However, within tree variability of growth strain was considerably higher than variability of other variables. Coefficients of variation for growth strains ranged from 21.7%–57.7%. Large variation within the tree implied that growth strains were not uniform around the periphery and along the tree height although all trees were straight and were grown under the same management practices. However caution should be taken in generalizing these results as they represent only one tree from each clone and do not represent within clone variability.

Within tree variability of longitudinal growth strains and basic density are shown in Figs. 2 and 3, respectively. In general, there was no specific trend in variation of longitudinal growth strain with tree height except that growth strains at 0.8 m height were higher than at 1.8 m in nearly all clones. However, large variation in growth strain was observed between clones in two bottom logs and this variation appeared to converge at around 3 m height. Larger variability in the lower portions of young trees might be attributed to differences in the extent of random formation of tension wood. Washusen et al. (2002) observed a large amount of tension wood in random arcs of bottom logs in *Eucalyptus globulus*. Presence of tension wood could result in higher basic density and high magnitude of growth strains in bottom logs.

Similar to growth strains, there was no generalized trend in density variation with tree height. Basic densities in clones 4 and 10 increased from 0.8 to 1.8 m height and declined at 2.8 m before increasing at greater heights. In contrast, clones 3, 6 and 10 exhibited declining trends in basic density with increasing height. This variable trend in basic density with tree height is not unusual because hardwoods typically display variation in wood basic density within a tree (Walker 2006).

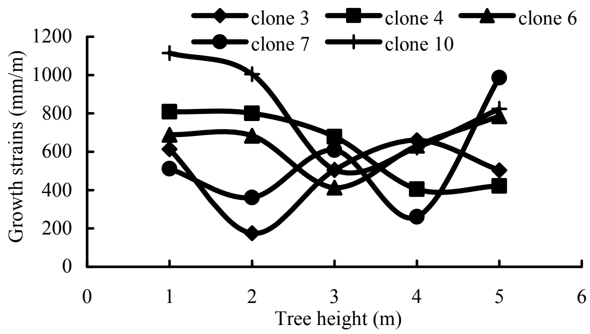

Fig. 2 Variation of growth strain with tree height

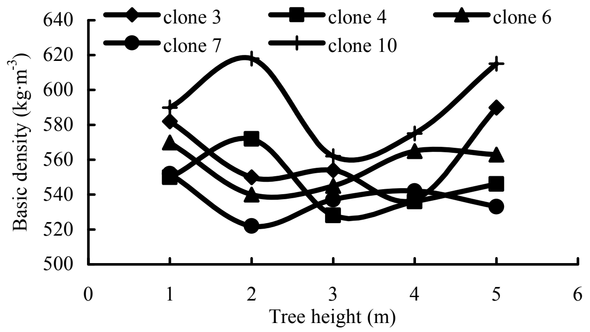

Fig. 3 Variation of basic density with tree height

Longitudinal growth strains differed on opposite sides of a log, suggesting variability in growth strain around the tree periphery. The relationship between growth strains on opposite sides of logs is shown in Fig. 4. Although there was strong correlation (correlation coefficient = 0.71) between the two strain values, the difference in growth strain between opposite sides ranged from 5%–200%. Such differences in the stem around the trunk periphery have been reported by many researchers. Nine to ten-fold differences in growth strain levels around the periphery at a given height have been reported by Boyd (1980) and Nicholson (1971) in large trees of diameter >40 cm of *Eucalyptus regnans* and *Eucalypyus nitens*. Raymond et al. (2004) also documented large variation around the periphery and up the stem in *Eucalyptus globulus* trees. Given the large amount of variation in growth strain within logs, the selection of the representative growth strain is of utmost importance to overcome problems related to growth stress. Raymond et al. (*ibid.*) suggested the use of the mean of the strain values measured on two sides as a suitable strategy for *Eucalyptus globulus*. Our results emphasize that although the logs were from very young trees (5-year old) and of small diameter, the difference in growth strain on opposite sides was substantial. This highlights the need to measure growth strain at a minimum of two opposite sides to get a reasonable estimate of the magnitude of growth strain in young trees. For further analysis, the average of two strains per log was taken as the mean strain value.

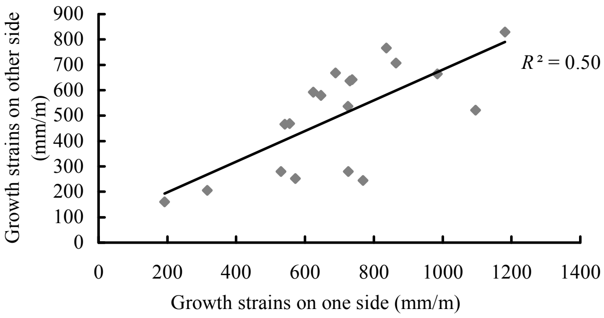

Fig. 4 Correlation of growth strain measured on opposite sides of logs

The relationship between tree growth and longitudinal growth strain has been investigated by several researchers. The scatter diagram of LGS with log diameter is shown in Fig. 5. The correlation between growth strain and log diameter was weak.

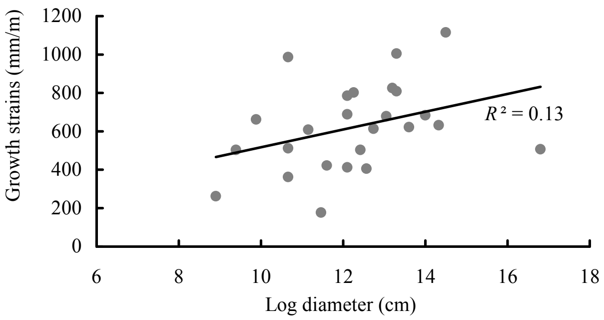

Fig. 5 Correlation between log diameter and growth strains

Correlation of basic density with growth strain is shown in Fig. 6. A significant positive relationship between the two variables was evident with a correlation coefficient of 0.55 (p < 0.01). There have been contrasting reports on the relationship between growth strain and basic density. Boyd (1980) reported significant relationships between growth strains and both density and MOE in reorienting stems of *Eucalyptus regnans,* while such relationships were absent for normal straight trees. Chafe (1990) documented positive correlation of growth strain with basic density in normal vertical stems of *Eucalyptus regnans* but found no such correlation in *Eucalyptus nitens*. Malan and Gerishner (1987) also documented positive correlation between LGS and density. Presence of tension wood in the stem could lead to a relationship between these two variables as tension wood is known to have high basic density compared to normal wood (Kubler 1987; Washusen et al. 2002) and high magnitude of growth stresses are linked with the presence of tension wood in eucalyptus species (Nicholson et al. 1975; Washusen et al. 2002).

It is generally believed that growth strains greater than 700 µm can lead to significant stress related degradation (Walker 2006) and only clone 10 among the studied clones exceeded this threshold. Therefore, clone 10, with high basic density, proved more suitable for pulping because its high growth strain values make its less suitable for sawn timber and solid wood products. All other clones were found to have lower strains. Clone 4 had the lowest growth strain values but it is one of the slowest growing clones (lowest log diameter). Clones 3 and 6 appeared to be candidate clones for sawn timber production as they had low growth strains and high growth rate. Also wood from these clones has been reported to have superior strength (Kothiyal et al. 2002).

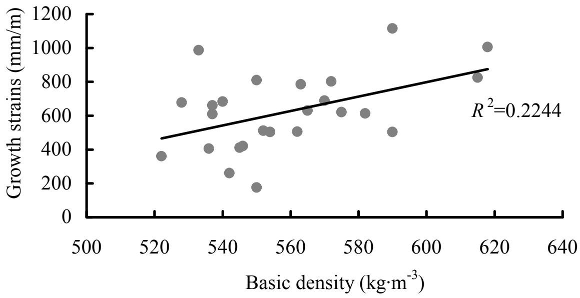

Fig. 6 Correlation of basic density with growth strains

Conclusion

Significant differences in longitudinal growth strains among five clones suggest the opportunity to select low-strain clones for propagation for solid wood applications. Timber produced from such clones would have fewer problems associated with growth stresses on sawing and product development. Moderate correlations of growth strain with basic density and log diameter implies the possibility of selecting clones for low stress levels without compromising on wood density or tree growth.

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